The Use and Variability of the Biotic Index to Monitor Changes in an Effluent Stream Following Wastewater Treatment Plant Upgrades

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Abstract
In 1982 the Madison Metropolitan Sewerage District began an intensive study of the Nine Springs wastewater treatment plant effluent stream Badfish Creek. The purpose of this study was to provide baseline data to monitor changes in the aquatic communities that may have occurred as a result of upgrades in the wastewater treatment plant that were completed in 1986.

The biotic index was determined for replicates of Kick net (6) and artificial substrate (3) samples at 4 sites along Badfish Creek at ca. 5 mile intervals from the headwaters progressing downstream. There was a definite improvement in water quality ratings at all stations from spring 1983 - spring 1988. Generally all sampling stations improved at least one water quality rating during this period and these improvements were probably due to upgrades in the wastewater treatment plant. There were some differences in spring and fall BI values, however these differences were not substantial. Artificial substrate samples generally had lower BI values and water quality ratings than the kick net samples taken at the same station and time. Approximately 39% of the comparisons of mean BI values of kick net and artificial substrate samples had different water quality ratings.

Kick net samples were overall slightly more variable (CV = 4.5%) than artificial substrate samples (CV = 2.7%). The standard deviation of the kick net samples was 0.31 which is comparable to other studies and the standard deviation of the artificial substrate samples was 0.19.

Introduction

The Madison Metropolitan Sewerage District (MMSD) began a detailed aquatic macroinvertebrate study in 1982 on Badfish Creek which is a receiving stream for the Nine Springs wastewater treatment plant (Fig. 1). The purpose of this study was to provide baseline data to monitor changes in the aquatic communities that may have occurred as the result of upgrades in wastewater treatment, that were completed in 1986. The District also anticipated that these biosurvey data might be an important tool in future years when examining necessary permit limits.

The MMSD treats wastewater from the City of Madison and surrounding communities, comprising ca. a 149 square mile service area, at the Nine Springs wastewater treatment plant. The plant is an activated sludge, advanced secondary treatment facility. The plant was upgraded in 1986 to gain advanced secondary treatment status which included: in-plant nitrification, larger plant size allowing longer retention time which lowered suspended solids and biological oxygen demand in the effluent, a switch from chlorination to ultraviolet disinfection, and bank stabilization (riprap) of three key sections of Badfish Creek.

Changes in effluent water quality due to the treatment plant improvements discussed above have been significant

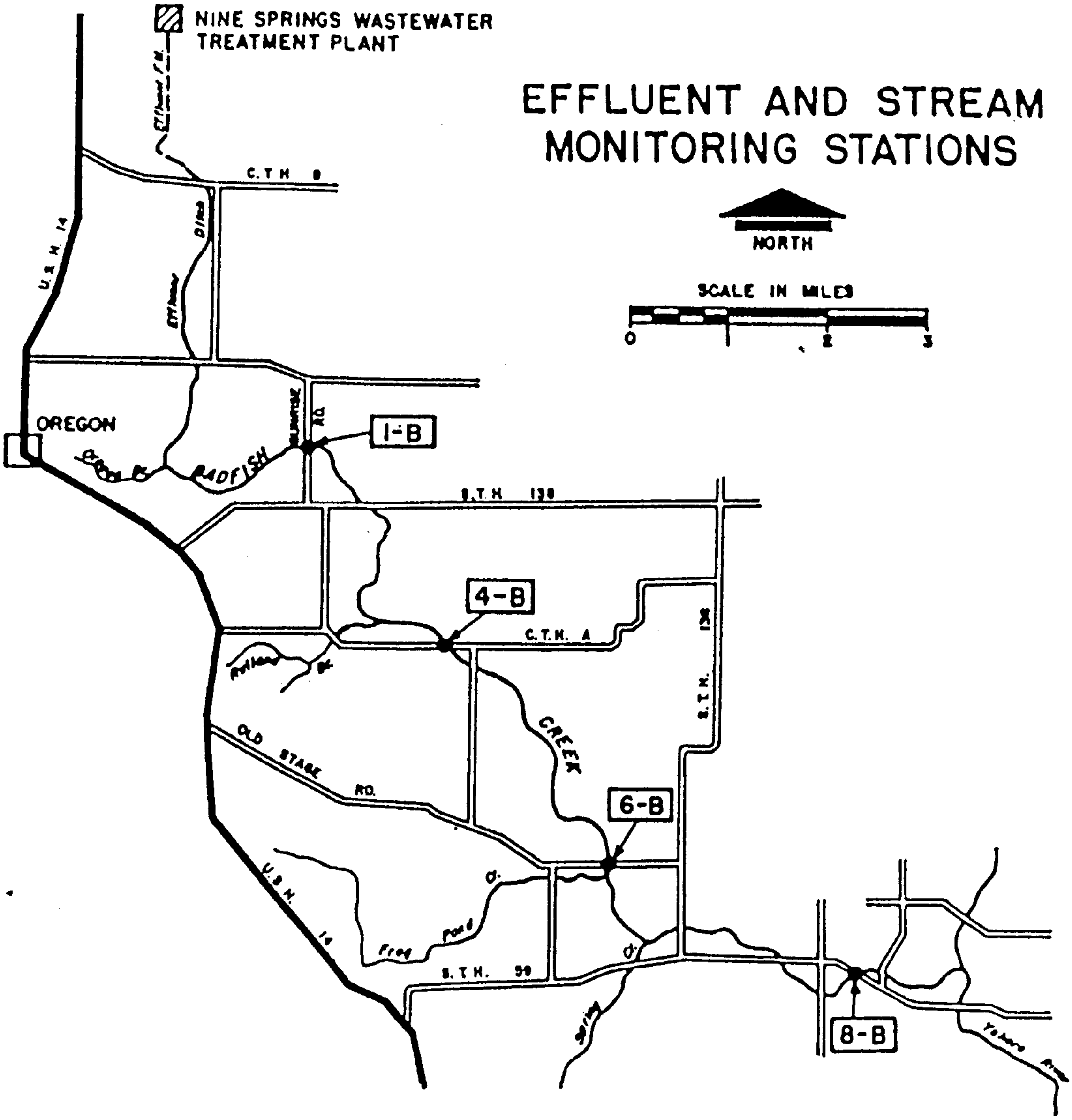

Figure 1. Biotic index sampling stations on Badfish Creek, Dane Co., Wisconsin.

and include a decrease in free ammonia from 9-15 ppm prior to 1985 to less than 0.2 ppm after April 1986. Total suspended solids also decreased substantially from 10-15 ppm prior to 1986 to ca. 5 ppm after April 1986. Biological oxygen demand decreased from 15-20 ppm prior to 1986 to 2-6 ppm after April 1986.

Treated wastewater from the Nine Springs facility has been discharged to the headwaters of Badfish Creek since December 1958. The effluent travels through an underground pipeline for ca. 5 miles to where it surfaces at the headwaters of Badfish Creek. The plant currently discharges 37 million gallons per day to the creek, which constitutes about 80% of the flow in the upper reaches. Inflows from 4 tributaries (Oregon Branch, Rutland, Spring and Frog Pond Creeks) and other surface runoff increases the flow to ca. 67 million gallons 20 miles downstream near the Yahara

River. The effluent constitutes ca. 50% of the flow prior to entering the Yahara River.

Materials and Methods
Four macroinvertebrate sampling sites were established on Badfish Creek which were positioned at ca. 5 mile intervals from the headwaters progressing downstream (Fig. 1). Biotic index (BI) samples (Hilsenhoff 1982, 1987) were taken in the spring (April) and fall (October) from spring 1983-spring 1988 (1988 fall samples were not included).

Aquatic macroinvertebrates were collected with a standard D-frame kick net which had a 12 in diameter opening and a 1 mm mesh bag. Samples were collected by kicking and disturbing the substrate upstream from the net for ca. one minute (Hilsenhoff 1982, 1987). Six kick samples were taken at each of the 4 sites using stratified random sampling procedures. One sample each was taken at the center and to the right and left of the center of the creek, 2 samples were taken near one bank and one sample was taken along the other bank for a total of 6 replicate kick net samples. After kick samples were taken they were vigorously washed in the net to remove fine sediments. The remaining debris and organisms were placed in labeled pint jars and preserved in 95% ethanol.

Artificial substrate samplers, similar to those described by Beak et al. (1973) were also used to collect BI samples. These samplers consisted of a 16 in dia., 1 in deep aluminum pizza pan with two expanded metal mesh inserts placed inside the tray one on top of the other, which served as the colonization substrates. The tray and inserts were attached to a cement anchor block that was placed on the stream bottom. These trays worked well because the problems of vandalism and organic debris build-up were minimized by their low profile. Three trays were placed across the creek at each sampling site. One tray each was placed at the center and near each bank at each sampling site 6 weeks prior to the fall and spring sampling dates to allow sufficient time for colonization to occur. A special retrieval top was used to retrieve the trays after the 6 week colonization period. This method ensured minimal loss of organisms during the retrieval process. The inserts and trays were rinsed into a 1 mm mesh soil sieve to remove fine sediments and retain the macroinvertebrates. The organisms and retained debris were then placed in labeled pint jars and preserved with 95% ethanol.

Aquatic macroinvertebrates were removed from debris in the laboratory and the contents of each sample were placed in a screen and rinsed to remove the alcohol and remaining fine sediments. The samples were then placed in a 10 in X 16 in white enamel pan and evenly spread over the pan bottom in water. A plexiglass grid (1.5 in high) was placed in the pan which partitioned the sample into 32 squares.

Squares were randomly selected for the kick net samples and all organisms were removed from each square until a total of 150 organisms were removed. If 150 organisms were removed before a square was completed the remaining organisms in the square were also included. Artificial substrate samples were also sorted in the enamel pan and 4 squares (ca. 1/8 of the sample) were randomly selected and all organisms in each square were picked. The grid insert was removed after the 4 squares were picked and the rest of the sample was sorted. The dominant organisms (over 30 count in the 4 squares) were not picked in the remaining sample but those picked from the 4 squares were multiplied by 8 to approximate the total numbers in the sample. All remaining non-dominant organisms were picked and counted.

Aquatic macroinvertebrates were identified to the lowest possible taxonomic unit. Chironomidae (Diptera) were slide mounted with Hoyers mounting media and allowed to clear to facilitate identification.

The BI was determined for each sample (Hilsenhoff 1982, 1987) and a mean BI was determined for each 6 replicate set of kick samples and 3 replicate set of artificial substrate samples. The BI was originally designed to detect problems with low dissolved oxygen caused by organic loading of putrescible wastes and it appears to work well for that purpose (Hilsenhoff 1977, 1982, 1987). It has been widely used by many state agencies and is the standard rapid bioassessment measure used by the WI Dept. of Natural Resources for water quality assessments. This index provides water quality ratings based on a numerical system of 0-10 with 0 indicating very good water quality and no organic pollution and 10 indicating very poor water quality and severe organic pollution (Table 1). The coefficient of variability (CV) and the standard deviation (STD) of the means were used to estimate data variability. The CV and STD were determined for each replicate set of kick net and artificial substrate samples for each sampling period.

Results and Discussion

Generally, BI values decreased and water quality ratings improved at all sampling stations from 1984 to 1988 and BI values increased at all stations from 1983 to 1984 (Table 2; Figs. 2-5). The most substantial improvements in water quality ratings occurred in the spring of 1985 and improvements continued through the spring of 1986 after which ratings for all stations appeared to stabilize (Table 3).

Station 1B had consistently the poorest water quality ratings of all stations (Table 3). This is not surprising since it has the greatest percentage of effluent of all stations and is closest to the MMSD wastewater treatment plant. Water quality at station 1B improved from very poor in 1983-1984 to fairly poor in the spring of 1988. Water quality at station 4B improved from a poor or very poor rating in 1984 to a fair rating from fall 1985 to spring 1988. Stations 6B and 8B improved from a general rating of fair - fairly poor in 1983-1984 to a fair - good rating in spring of 1988. Stations 48, 6B and 8B generally had similar water quality ratings after spring of 1985 (Table 3). These improvements in water quality from 1983-1988 are most likely due to the improvements and upgrades in the MMSD treatment plant including decreases in free ammonia, total suspended solids, and biological oxygen demand, and the change from chlorination to ultraviolet light for disinfection.

Fall samples generally had slightly lower mean BI values (determined from the replicate sets) than spring samples. Fifty five percent of the kick net samples and 65% of the artificial substrate samples had lower BI values in the fall than spring (Table 2; Figs. 6-9), however only 16% and 18% respectively of the kick net and artificial substrate sample comparisons of spring and fall data had different water quality ratings (Table 3). The absolute mean difference between spring and fall kick net samples was 0.47 ± 0.43 and 0.75 ± 0.77 for artificial substrate samples. Hilsenhoff (1988) recommended that BI samples be taken 60 days after the 440 degree day accumulation in warm-water streams and 45 days after the 1050 degree day accumulation in cold-water streams. Badfish Creek is classified as a warm-water stream and the fall samples were taken at least 45 days after the 440 degree day accumulation.

Approximately 39% (17) of the 44 comparisons of mean BI values from replicate sets of artificial substrate (3 replicates) and kick samples (6 replicates) taken at the same time and stations had different water quality classifications. Artificial substrate

Table 1. Water quality classifications for the biotic index (from Hilsenhoff 1987).

BIOTIC INDEX VALUES	WATER QUALITY CLASSIFICATION	DEGREE OF ORGANIC POLLUTION
0.00-3.50	**Excellent**	No apparent organic pollution
3.51-4.50	**Very Good**	Possible slight organic pollution
4.51-5.50	**Good**	Some organic pollution
5.51-6.50	**Fair**	Fairly significant organic pollution
6.51-7.50	**Fairly Poor**	Significant organic pollution
7.51-8.50	**Poor**	Very significant organic pollution
8.51-10.00	**Very Poor**	Severe organic pollution

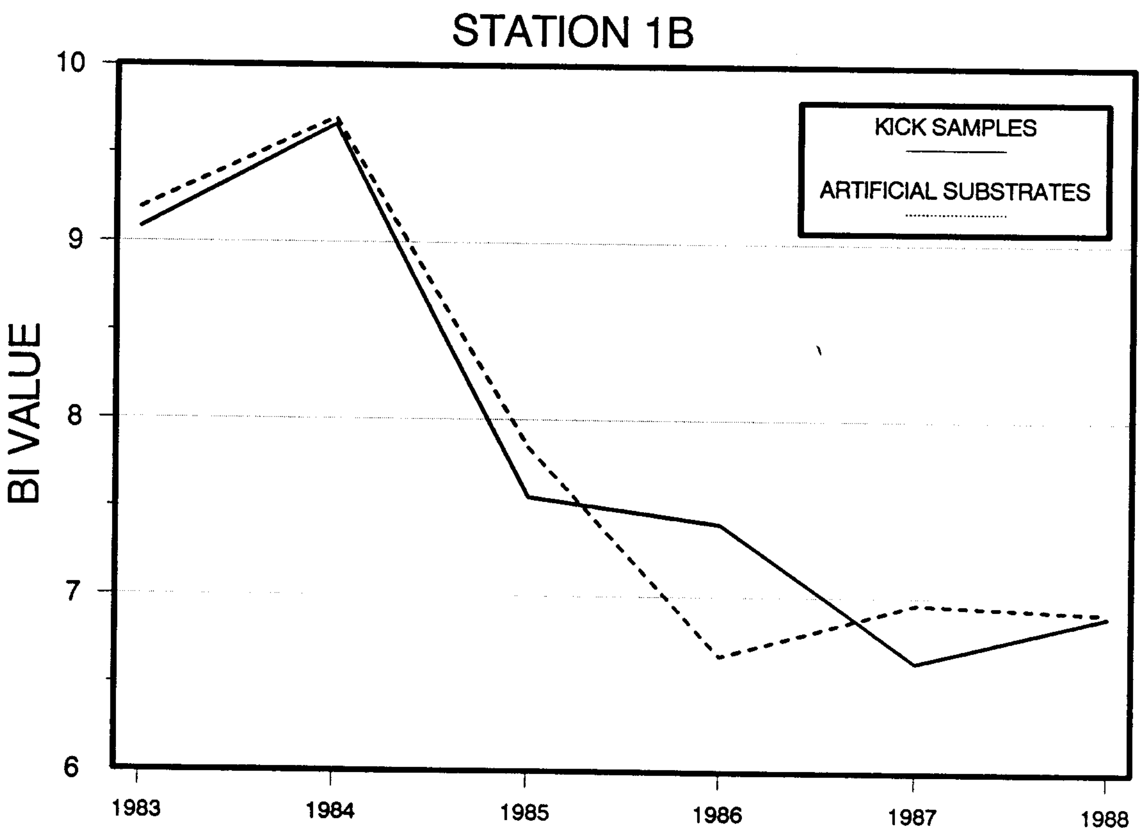

Figure 2. Mean BI values of the replicate set of kick net and artificial substrate samples (spring and fall data combined) from spring 1983 - spring 1988 for sampling station 1B from Badfish Creek, Dane Co., Wisconsin.

Table 2. Seasonal BI values by year and station (values are means and standard deviations of the replicate sample sets - 6 samples for kick net and 3 samples for artificial substrates).

Year/Season Type of sample	Sampling Stations 1B	4B	6B	8B
1983/Spring				
KS[1]	9.23 ± 0.32	7.12 ± 0.44	6.93 ± 0.16	6.57 ± 0.22
AS[2]	9.25 ± 0.30	6.37 ± 0.31	6.80 ± 0.02	6.47 ± 0.11
1983/Fall				
KS	8.92 ± 0.24	7.10 ± 0.19	6.84 ± 0.22	6.73 ± 0.39
AS	9.12 ± 0.12	8.03 ± 0.42	7.00 ± 0.10	6.09 ± 0.07
1984/Spring				
KS	9.51 ± 0.22	7.82 ± 0.83	7.43 ± 0.22	6.65 ± 0.30
AS	9.57 ± 0.32	7.09 ± 0.37	6.91 ± 0.09	6.35 ± 0.13
1984/Fall				
KS	9.81 ± 0.05	9.19 ± 0.12	8.42 ± 0.39	7.15 ± 0.27
AS	9.82 ± 0.03	9.73 ± 0.07	8.31 ± 0.83	6.46 ± 0.22
1985/Spring				
KS	8.40 ± 0.90	6.74 ± 0.57	6.69 ± 0.15	6.25 ± 0.12
AS	9.05 ± 0.21	6.32 ± 0.09	6.51 ± 0.41	6.10 ± 0.06
1985/Fall				
KS	6.71 ± 0.10	6.47 ± 0.02	6.27 ± 0.27	6.68 ± 0.60
AS	6.62 ± 0.09	6.23 ± 0.10	6.37 ± 0.18	5.93 ± 0.12
1986/Spring				
KS	7.70 ± 0.62	6.35 ± 0.20	6.09 ± 0.32	6.38 ± 0.51
AS	6.79 ± 0.30	5.97 ± 0.09	6.09 ± 0.13	5.97 ± 0.16
1986/Fall				
KS	7.12 ± 0.40	6.33 ± 0.14	5.54 ± 0.23	6.17 ± 0.42
AS	6.52 ± 0.28	5.83 ± 0.20	5.70 ± 0.60	5.44 ± 0.17
1987/Spring				
KS	6.61 ± 0.09	6.30 ± 0.24	6.40 ± 0.30	6.16 ± 0.09
AS	6.22 ± 0.19	6.10 ± 0.02	6.27 ± 0.13	6.11 ± 0.07
1987/Fall				
KS	6.64 ± 0.14	6.12 ± 0.32	5.64 ± 0.18	5.72 ± 0.56
AS	7.69 ± 0.25	5.55 ± 0.24	5.13 ± 0.05	5.16 ± 0.06
1988/Spring				
KS	6.89 ± 0.46	6.20 ± 0.32	5.79 ± 0.18	5.98 ± 0.38
AS	6.91 ± 0.27	5.94 ± 0.18	5.41 ± 0.11	5.89 ± 0.22

[1] Kick net samples

[2] Artificial substrate samples

Table 3. Seasonal water quality ratings by year and station (water quality ratings from Hilsenhoff 1987).

Year/Season	Sampling Stations			
Type of sample	1B	4B	6B	8B
1983/Spring				
KS[1]	Very Poor	Fairly Poor	Fairly Poor	Fairly Poor**
AS[2]	Very Poor	Fair*	Fairly Poor	Fair*
1983/Fall				
KS	Very Poor	Fairly Poor	Fairly Poor	Fairly Poor
AS	Very Poor	Poor	Fairly Poor	Fair
1984/Spring				
KS	Very Poor	Poor	Fairly Poor*	Fairly Poor**
AS	Very Poor	Fairly Poor	Fairly Poor	Fair*
1984/Fall				
KS	Very Poor	Very Poor	Poor*	Fairly Poor
AS	Very Poor	Very Poor	Poor*	Fair*
1985/Spring				
KS	Poor*	Fairly Poor	Fairly Poor**	Fair
AS	Very Poor	Fair*	Fairly Poor*	Fair
1985/Fall				
KS	Fairly Poor	Fair*	Fair	Fairly Poor**
AS	Fairly Poor**	Fair	Fair**	Fair
1986/Spring				
KS	Poor	Fair*	Fair	Fair
AS	Fairly Poor	Fair	Fair	Fair
1986/Fall				
KS	Fairly Poor	Fair*	Fair**	Fair*
AS	Fairly Poor**	Fair	Fair**	Good*
1987/Spring				
KS	Fairly Poor**	Fair*	Fair*	Fair
AS	Fair	Fair	Fair	Fair
1987/Fall				
KS	Fairly Poor**	Fair	Fair**	Fair
AS	Poor**	Fair**	Good	Good
1988/Spring				
KS	Fairly Poor	Fair	Fair	Fair
AS	Fairly Poor	Fair	Good*	Fair

[1] Kick net samples
[2] Artificial substrate samples
* Ratings which missed the next poorer water quality rating by 0.20 BI units
** Ratings which missed the next better water quality rating by 0.20 BI units

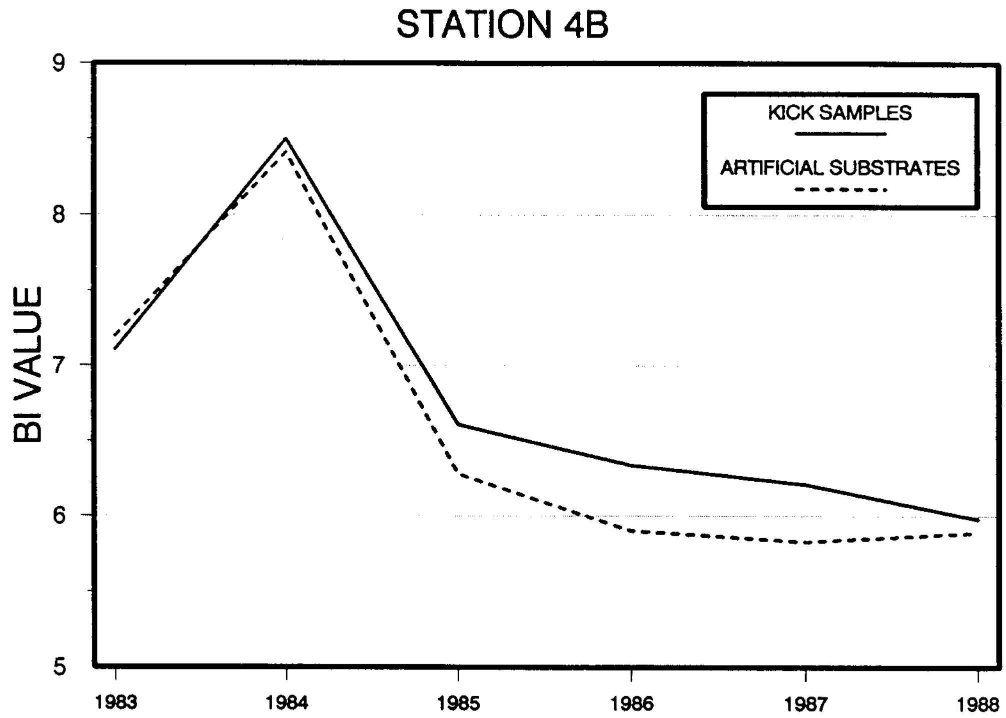

Figure 3. Mean BI values of the replicate sets of kick and artificial substrate samples (spring and fall data combined) from spring 1983 - spring 1988 for sampling station 4B from Badfish Creek, Dane Co., Wisconsin.

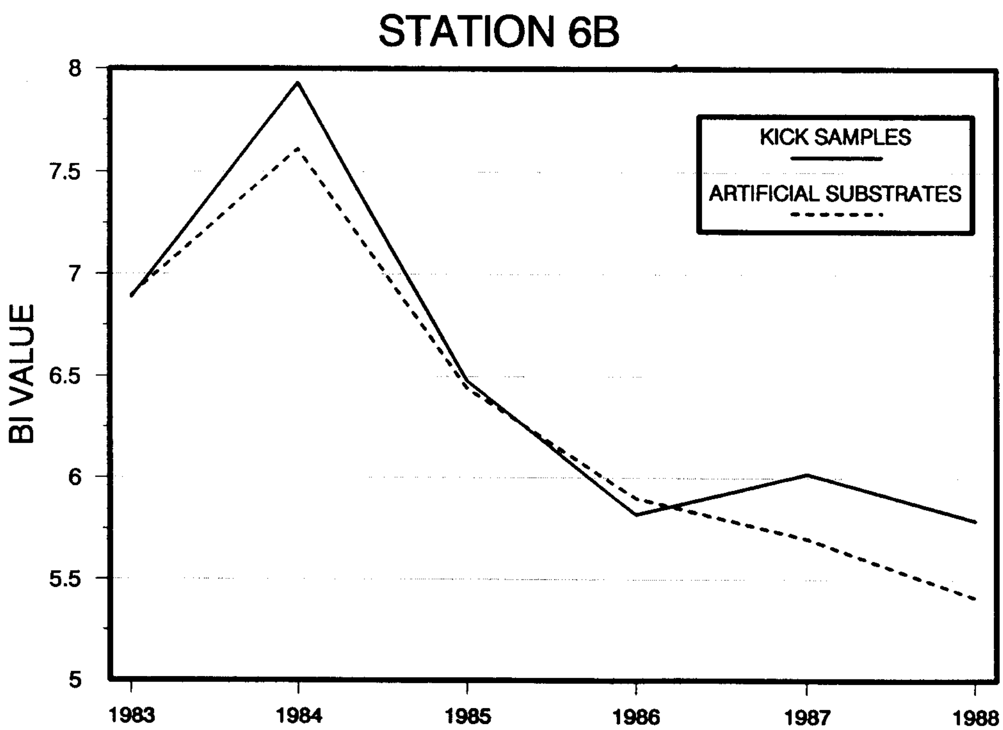

Figure 4. Mean BI values of the replicate sets of kick and artificial substrate samples (spring and fall data combined) from spring 1983 - spring 1988 for sampling station 6B from Badfish Creek, Dane Co., Wisconsin.

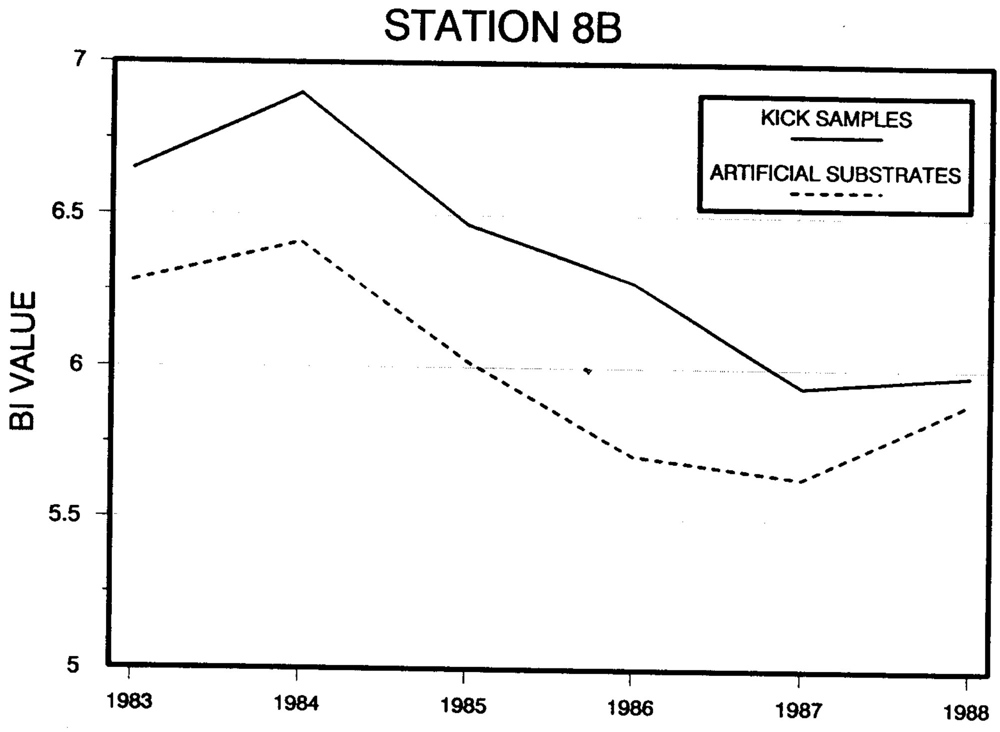

Figure 5. Mean BI values of the replicate sets of kick and artificial substrate samples (spring and fall data combined) from spring 1983 - spring 1988 for sampling station 8B from Badfish Creek, Dane Co., Wisconsin.

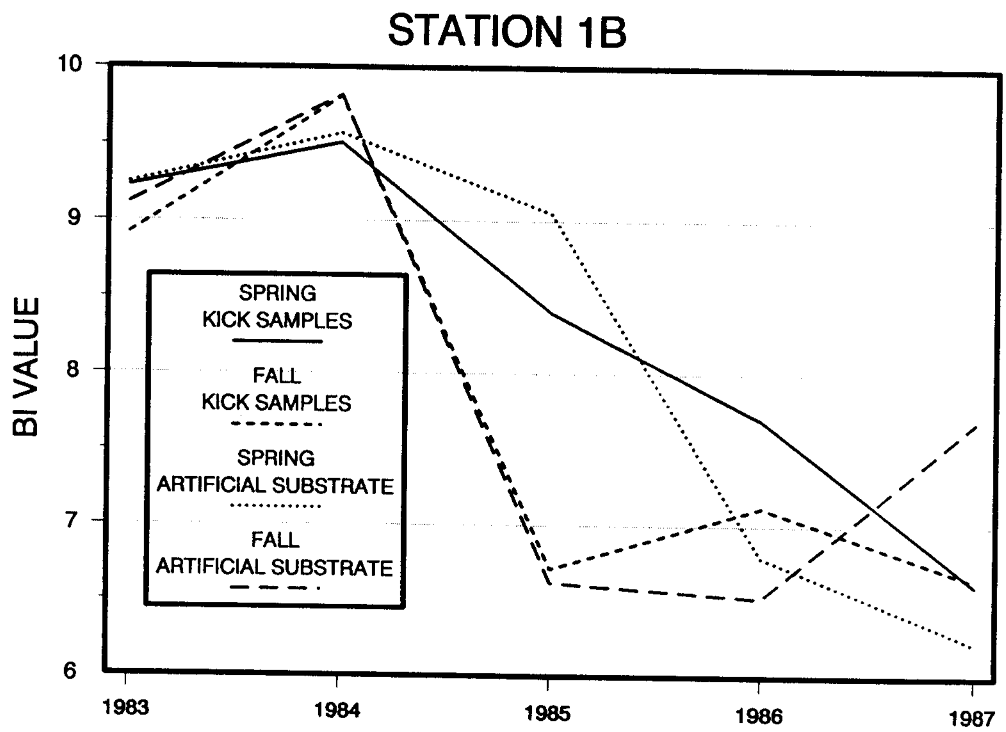

Figure 6. Mean BI values of the replicate sets of kick and artificial substrate samples for spring and fall from spring 1983 - spring 1988 for sampling station 1B from Badfish Creek, Dane Co., Wisconsin.

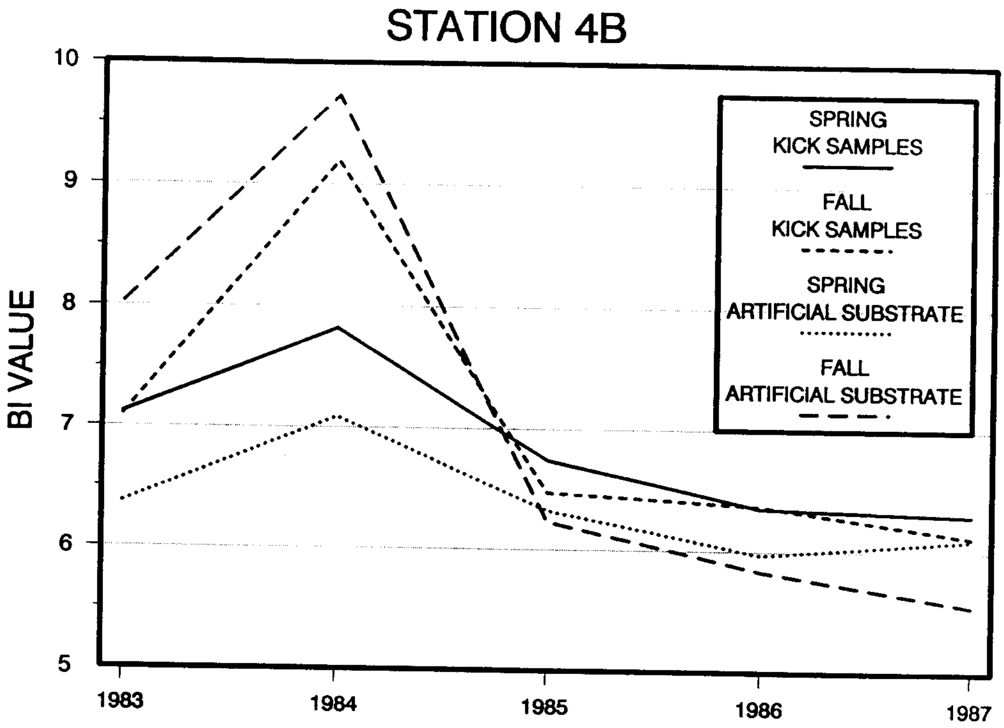

Figure 7. Mean BI values of the replicate sets of kick and artificial substrate samples for spring and fall from spring 1983 - spring 1988 for sampling station 4B from Badfish Creek, Dane Co., Wisconsin.

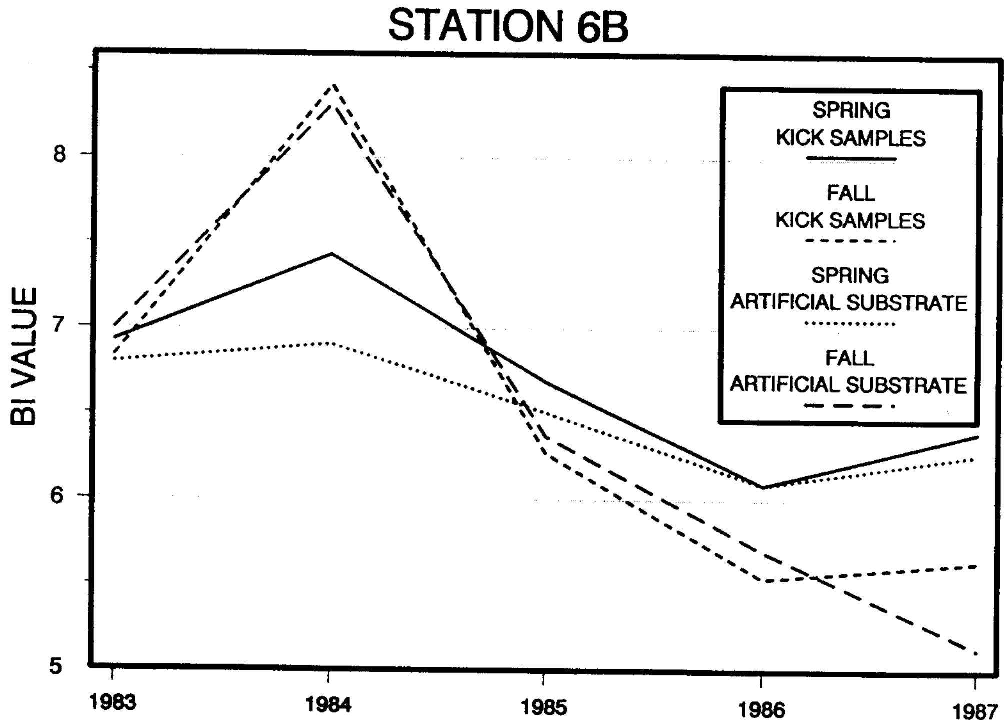

Figure 8. Mean BI values of the replicate sets of kick and artificial substrate samples for spring and fall from spring 1983 - spring 1988 for sampling station 6B from Badfish Creek, Dane Co., Wisconsin.

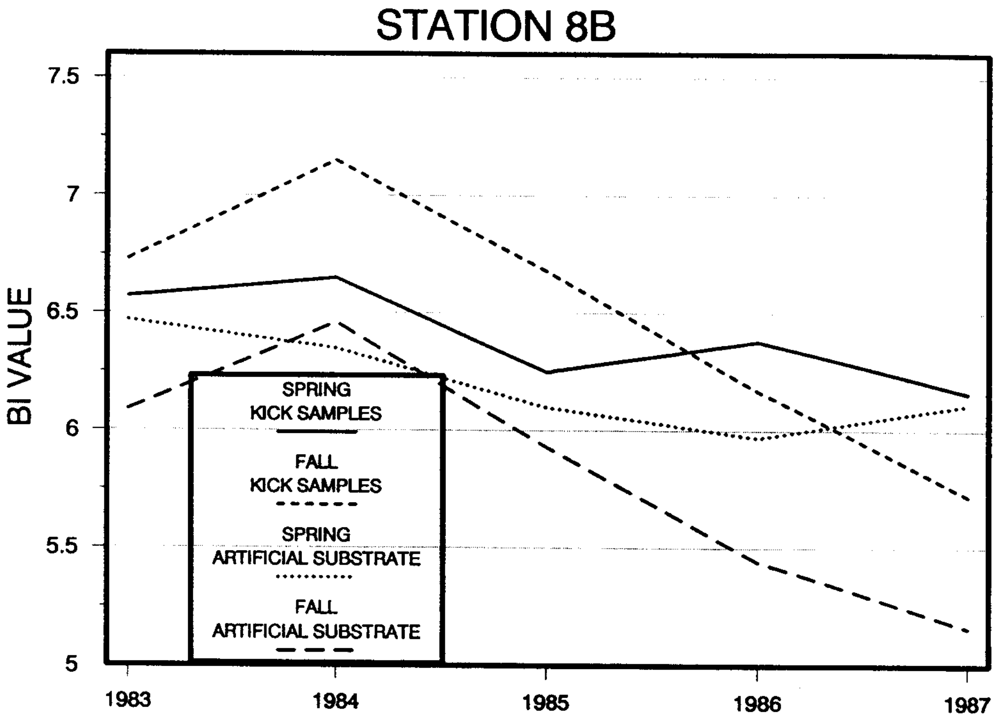

Figure 9. Mean BI values of the replicate sets of kick and artificial substrate samples for spring and fall from spring 1983 - spring 1988 for sampling station 8B from Badfish Creek, Dane Co., Wisconsin.

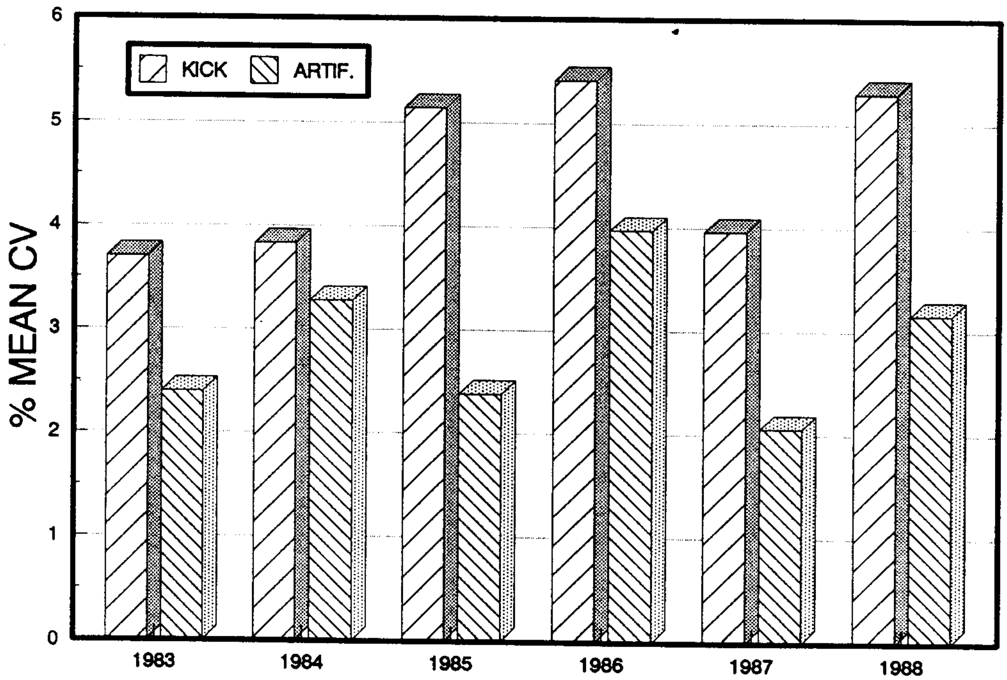

Figure 10. Annual mean coefficient of variation (CV) of the replication sets of kick net and artificial substrate samples (spring and fall and all station data combined) from spring 1983 - spring 1988 from Badfish Creek, Dane Co., Wisconsin.

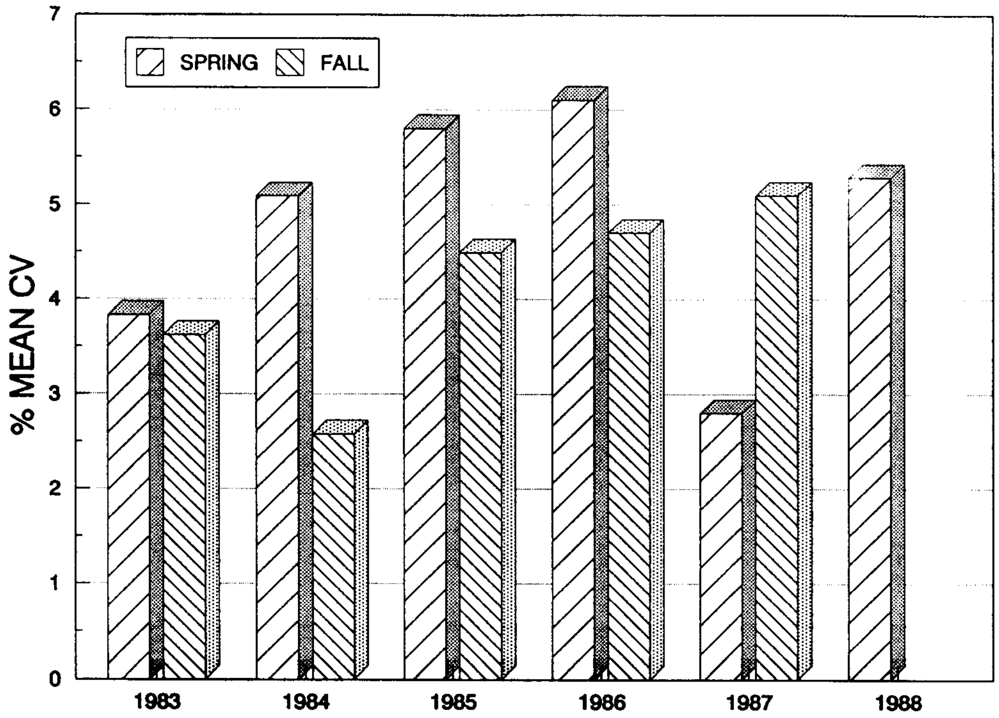

Figure 11. Seasonal mean coefficient of variation (CV) of kick net samples from spring 1983 - spring 1988 from Badfish Creek, Dane Co., Wisconsin.

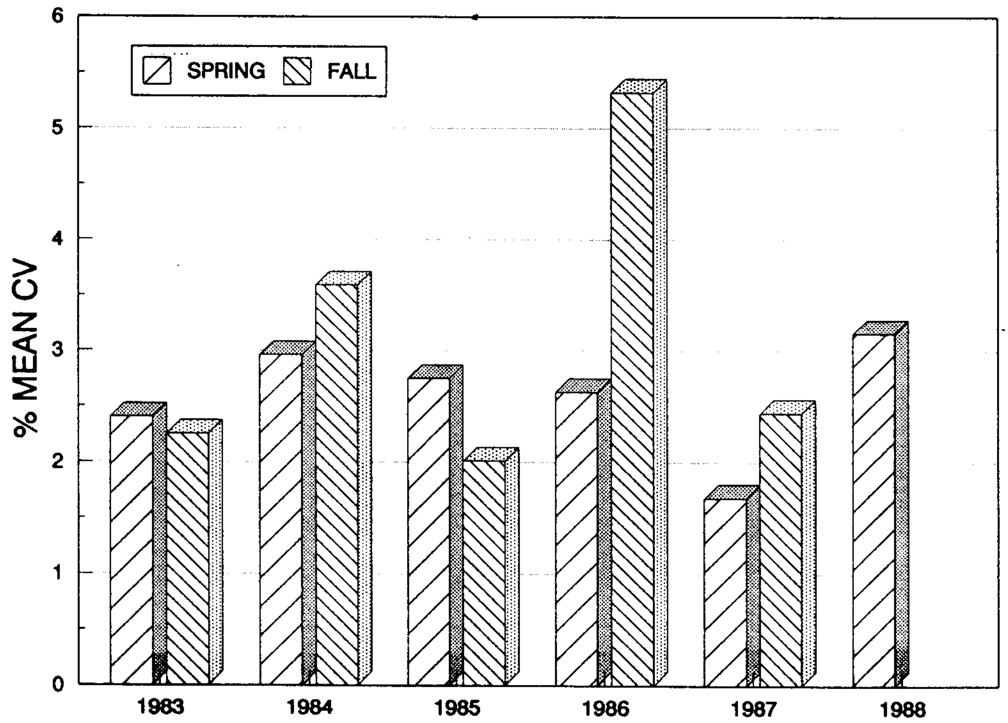

Figure 12. Seasonal mean coefficient of variation (CV) of artificial substrate samples from spring 1983 - spring 1988 from Badfish Creek, Dane Co., Wisconsin.

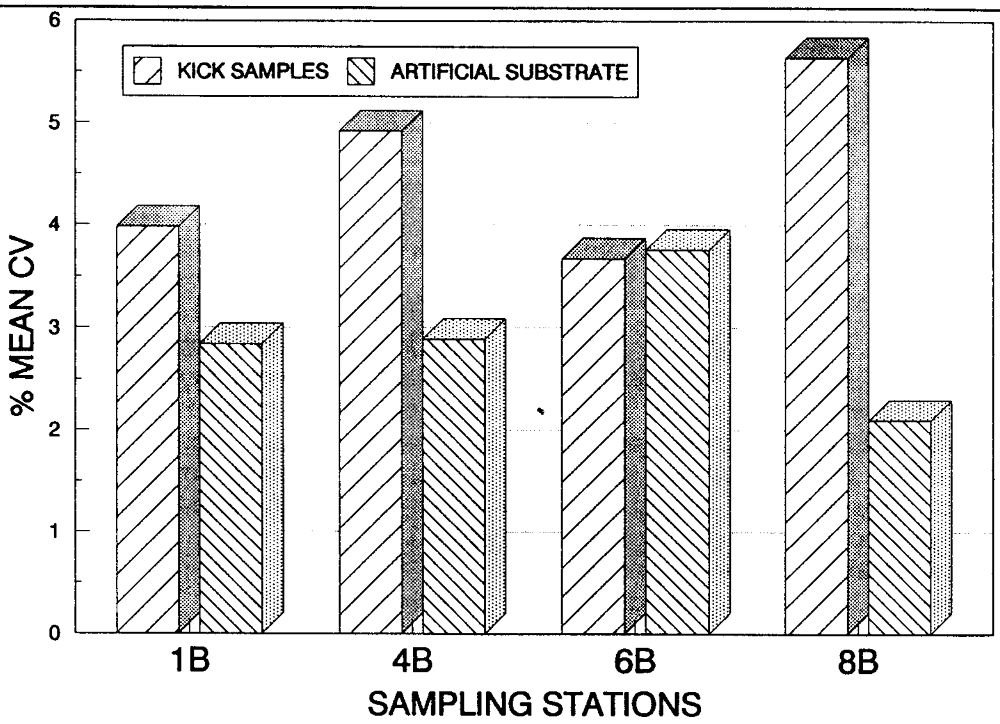

Figure 13. Mean coefficient of variation (CV) of the replicate sets of kick net and artificial substrate samples for each station (annual and seasonal data combined) from Badfish Creek, Dane Co., Wisconsin.

samples had a one range cleaner water quality classification than the kick samples in 15 of the 17 comparisons that were different. Only 2 of artificial substrate samples provide a poorer (one range) water quality rating than the kick samples (Table 3; Figs. 2-9). The absolute mean difference between the means of the BI determined from the replicate sample sets for kick net and artificial substrate samples taken at the same times and stations was 0.37 ± 0.29.

The overall variability of the kick samples (mean CV = 4.5%) was greater than the artificial substrate samples (mean CV = 2.7%) based on comparisons of the means of 6 and 3 replicate sets for kick and artificial substrate samples respectively from spring 1983-spring 1988 (Fig. 10). This slight difference in variability may have been due to the different number of replicates taken for artificial substrate and kick net samples, or to differences inherent in the types of samplers. The overall standard deviation of 6 replicate sets of kick samples was 0.31 which is comparable to values of 0.24 and 0.28 reported by Hilsenhoff (1988) and Szczytko (1988) respectively for biotic index samples. The overall standard deviation of the artificial substrate samples was 0.19.

The variability of biotic index values of replicate sample sets combined from 1983-1988 was slightly lower in the fall (CV = 4.10%) than spring (CV = 4.83%) for kick samples and greater in the fall (CV = 3.17%) than spring (CV = 2.62%) for artificial substrate samples (Figs. 11 & 12). These differences are small and were probably related to sampling and sorting techniques or to the heterogeneous distribution of the macroinvertebrates.

The CV among replicate sample sets was variable from 1983-1988 for both kick net and artificial substrate samples and no annual trends were apparent (Fig. 10). The CV ranged from 3.84-5.41% for kick samples and from 2.06-3.97% for artificial substrate samples during the course of this study. Sampling station 8 had the lowest combined (all years and seasonal data combined) variability (CV = 2.1%) for artificial substrate samples and station 6 had the lowest variability (CV = 3.7%) for kick samples (Fig. 13). There were no obvious trends in variability related to the sampling stations in this study.

Conclusions

There was a definite improvement in water quality ratings determined from BI values in Badfish Creek from spring 1983- spring 1988. Basically all sampling stations improved at least one water quality rating better during the course of this study. These improvements were most likely related to upgrades in the wastewater treatment plant discussed above and the water quality ratings observed in the spring of 1988 are probably the water quality ratings which will continue in the future. Station 1B had the lowest water quality ratings of all stations and station 4B, 6B and 8B had similar ratings by the end of this study.

Generally there were some differences in fall and spring BI values, however we do not view these differences as substantial since part of the variability can be explained by the standard deviation of the means. Also only 16% of the kick net and 23% of the artificial substrate sample comparisons between spring and fall had different water quality ratings and many of the water quality ratings that were different missed the water quality rating of the other season by only 0.20 BI units or less (Table 3).

Artificial substrate samples generally had lower BI values and water quality ratings than the kick net samples taken at the same time and sampling station. These differences were probably related to the different types of samplers and sorting techniques used. In many cases water quality ratings from kick or artificial substrate samplers missed the water quality rating of the other type of sampler by only 0.20 BI units or less (Table 3).

Kick net samples were slightly more variable than artificial substrate samples (mean CV determined from the sets of replicate samples). These differences in variability (1.8%) were small and were probably related to sampling and sorting techniques. The overall standard deviation of the kick net samples were comparable to other studies. The variability of BI samples is lower than most other benthic community metrics currently used for water quality assessment (Szczytko 1988).

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